Third Edition August 2005 Acknowledgements

This third edition of my *Solar Design Manual* brings many aspects of recent development up-to-date in the manual. Particularly important are the major additions in the photovoltaic section. For that, I credit Home Power Magazine, especially Scott Russell, who allowed me to use his excellent guide "Simplifying Solar Electric Systems," published in the January-February 2005 issue of Home Power Magazine available at www.homepower.com. Also strengthened are aspects of the present circumstances anticipating "Peak" oil production worldwide and its ensuing pressures on our civilization and economy. Additions regarding the new thrust nationwide and worldwide toward developing zero net energy homes are also included.

As always I want to acknowledge Anthea Craven's competent support as assistant to the housing specialist at Cooperative Extension Service. Her capabilities and assistance are indispensable and greatly valued. Amy Simpson, who is with Extension Communications, skillfully redesigned the manual cover page to a more Alaskan photovoltaic solar "look."

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Deirdre Helfferich of the School of Natural Resources and Agricultural Sciences did a peer quality edit that measurably improved the clarity of this 3rd edition.

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Rich Seifert

Richard D. Seifert, responsible author, August 2005

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Cover photo: by Greg Egan. Print of a photovoltaic system installation on a workshop in Wasilla that Greg made for a couple living off-grid.

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foreword

This new edition of *A Solar Design Manual for Alaska* adds much more detail in the main text. So much has changed since the first edition, and almost as much since the second edition, that this new foreword was necessary to place these many crucial factors in housing quality, sustainability, and the implications of world peak oil production at the forefront of using solar design and technologies, and their integration into housing. Solar energy applications, as a major element of renewable energy, will become ever more important as a design staple, as major increases in fossil fuel costs occur, and demand for fuels outstrips supplies. Many informed thinkers and oil watchdogs are convinced that the peak of oil production worldwide is at best only a few years away, and some think it is already upon us in 2005. Regardless, it is inevitable, and the more we begin to lessen our dependence on fossil fuels, the more secure and financially safe we'll be. Energy security will become a new goal, and its meaning will become very clear to those who aren't paying attention to their fossil fuel dependence.

As I assemble this new manual foreword from the major resources about the energy situation in the world and the importance of energy conservation, oil prices are surging toward $60 a barrel (March 2005). Recently new record high prices for oil worldwide have resulted from the immediate shortfall cause induced by the Yukos Russian oil crisis. All of this is a portent of what may get much worse in the near future.

In order to grasp the limits of our present "oil age" it is important to understand an oil reservoir depletion curve, a concept that was made famous by M. King Hubbert, a petroleum geologist with Shell Oil. Hubbert became famous for his ability to predict the development, the peak time of production, and the ultimate decline of oil reserves, first in the United States and then worldwide. The Hubbert Curve, as it's become known, describes when oil production will peak and how quickly it will decline depending on accelerated use. It is very possible that we are at, or very near the Hubbert Peak of oil production in the world. This will have enormous implications for our future. It is for this reason that I begin this discussion with oil price and supply concerns. If oil supplies are declining, while demand is increasing, and the United States is importing more than half its oil, well, the problem will soon get very testy. In fact we are already in a very serious and vulnerable situation, which we ignore to our peril. Oil prices will rise, as supplies drop. A graphic depiction of the Hubbert curve is shown in Figure 1 below.

It is important to comprehend the information contained in the Hubbert curve. The curve describes the annual production of world oil. The peak of this production, the point at which more oil will be produced than in any other year, is shown where the curve is at its "peak." This will occur (or has occurred already) at a certain date. Perhaps the most important of the several curves in Figure 1 is the light uppermost one, which is for the entire world oil peak. This presentation shows clearly the peak will occur sometime between 2001 and 2006. After the peak, production does not stop, but it does decline at a steady rate. This is the crucial factor of the Hubbert curve insight: oil production will never increase or even be equal to the rate achieved at the peak. Although the demand will increase, the production not only will not, but CANNOT increase! It will steadily decline after the peak. This will undoubtedly mean great pressure on world oil supplies

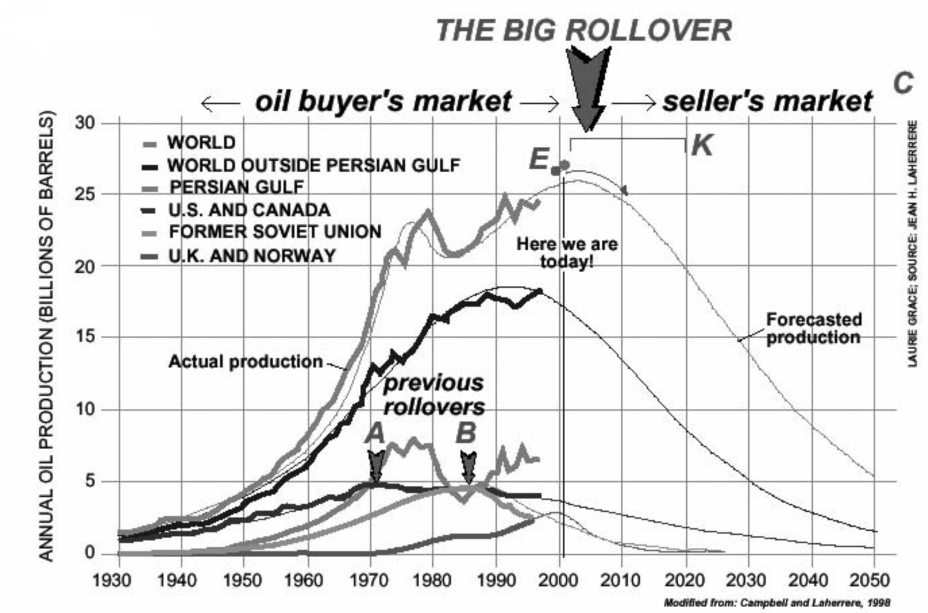


Figure 1. "The Big Rollover," from increasing world oil production to declining world oil production, derived from predictive math developed by M. King Hubbert. Original source, Campbell and Laherre, (1996).

and prices, and possible shortages and resource conflicts as awareness and competition for these dwindling oil resources increases with each passing year. We won't run out of oil. Rather, it will become a more scarce, valuable, and expensive commodity. This is a VERY serious issue, and awareness of it should be paramount in our energy and economic planning for the future.

Alaska is in a position to cushion itself rather well from this threat, because we have our own supplies and our own production within the state. This will be enormously valuable to us in the short term. But we will also be subject to oil price increases since we sell our oil at the world price. All of this makes the issue of energy conservation and efficient use of the energy we have extremely important for the future. It all comes down to making the best possible investments now in energy conservation, good housing, good control systems, good commercial buildings, and energy efficient transportation systems. Whatever we do now will pay back enormously in both the short and long terms. The lower we can make our energy demand now, the better off we will be economically, socially, politically, and militarily. An additional bonus is that we will also be more secure. Much of discussion used to make this case comes from an article by Robert Freeman published on March 1, 2004 on the www.commondreams.org website. It is titled: "*Will the End of Oil mean the End of America*?" Freeman begins by quoting Robert Pirsig from his fabulous book *Zen and the Art of Motorcycle Maintenance*. Pirsig relates the story of a South American Indian tribe that has devised an ingenious monkey trap. The Indians cut a small hole in one end of a coconut and stuff it with sweetmeats and rice. Then they fasten the other end of the coconut to a stake and place it in a clearing, waiting for a monkey to come along. Now, the monkey can get its hand into the coconut *just barely*, but stuffed with booty, it cannot pull the hand back out. The monkey of course has a choice to release the booty and escape. But somehow the monkey never quite understands this. The Indians easily walk up to the monkey and capture it. As the Indians approach their successful trap, the monkey screams in horror, not only in fear of its captors, but equally as much in recognition of tragedy of its own lethal but still unalterable greed.

Why is this story of value in our present situation? It's because the monkey cannot recognize that it's created its own trap. It chooses wrongly by dooming itself on its short-term fixation of the relatively paltry pleasure, not knowing that it's going to meet its death because of the choice it has made. The relevance of this wonderful allegorical tale is obvious for America, which has its own hand in a coconut and one that may doom it just as surely as the monkey. And that coconut, of course, is our dependence on cheap oil in a world where cheap oil is in rapid decline.

So what do we do? Can we move to a new sustainable economy quickly enough and get a new sustainable basis for civilization? Or do we have the hand in the coconut such that we will force the rest of the world to give us secure, stable supplies, militarily?

It may shock many people who are not well informed about the realities of world oil supplies, that we are running out of *cheap* oil rather quickly. In the year 2000 global oil production stood at 76 million barrels per day, but by 2020 demand is forecast to reach 112 million barrels per day, an increase of 47 percent. Is it possible to even get there from here? Estimates of the date of peak global production vary, with some experts saying it may have already occurred as early as the year 2000. But virtually all experts believe it will most certainly occur before the end of this decade (Freeman, 2004). If we even come close to producing oil to meet the huge demand predicted for 2020, it certainly won't be with *cheap* oil.

As the depletion proceeds, the demand for oil in the world is increasing on the order of two percent a year. A two percent growth rate is a doubling in 35 years, so it's not surprising that in a mere 15 years, 2020, you would expect a 47 percent increase. All this portends much for the housing and commercial building sector of the economy, which is together approximately 50 percent of all U.S. energy use. There are also huge implications for energy security. If we are increasing our demand at a time when supplies are decreasing, we will continue to accelerate our dependence on foreign oil supplies. Already we require 50 percent plus of our oil in the United States from foreign supplies. In Alaska, we are very fortunate. If we play our cards right, we will have enough for a few decades at least, even if it is at the world price, because it's produced here and our demand is small compared to the rest of the country.

The choice for building a sane future is what Freeman calls "energy reconfiguration." Literally, this is a retrofitting of the nation's buildings, both commercial and residential, to double their energy efficiency. It means a crash program to shift the transportation system, cars and trucks, to a fleet that uses perhaps half as much oil per year. And this is well within the reach of current technology. Energy reconfiguration could mean using biotechnology to develop crops that require less fertilizers, pesticides, herbicides, and machinery to harvest. It means refitting the industrial and commercial processes, lighting, heating, appliances, and automation so that they too consume far less energy than they do today. But more directly and practically, it simply means increasing efficiency, reducing consumption, and building a sustainable long-term alternative system in every arena in which the economy uses oil. Buildings and architecture are 50 percent of this problem, and it can be solved with energy-conserving, solar-integrated, healthy, materials-efficient design and construction.

Much of this scenario of energy reconfiguration also plays very well into the case I make in this manual. It is also deeply explored and well described in a recent major work by Amory Lovins, et al., from the Rocky Mountain Institute, which describes how to succeed in converting the U.S. energy economy to an efficient, profitable system without major upheavals and minimal security risk. Aptly named "Winning the Oil Endgame," this is the most optimistic and feasible of the futuristic concepts for making the transition to minimal oil dependence. (This text is available as a free download at the website: www.oilendgame.org/ReadTheBook.html).

By reducing demand for *all* energy, the renewable forms of energy, the sustainable alternatives, become more affordable. The less total energy a home requires, the easier it is to accommodate that need with renewable energy. This "energy reconfiguration" would not only be a boon to construction and to job creation, it would have incalculable benefits to our security, our health, the economy, and the environment. In Alaska this situation is even more pressing because of our climate. Our climate inherently demands more energy use per capita, and our driving habits, our transportation system, our common use of aircraft for travel and transportation of our goods—all lead to an extremely high energy consumption per capita, perhaps the highest in the world. So where do we put our greatest efforts?

A top priority might be to look at the idea of making houses as close to "zero net energy" consumption as possible. So what is a "zero net energy house"? The definition of a zero net energy house is "a house designed to bring the house's annual energy use to as nearly energy neutral conditions as possible." This requires that over a year, the house produce as much energy onsite (through solar, wind, or other renewable options) as it uses throughout the year. The net energy use of the house, the net energy exchange across the boundary of the building, is designed to be as close to zero as possible. This of course, implies superinsulated houses, very high efficiency lighting and ventilation systems, and superb appliances. And appliances have in fact improved markedly over the last decade due to federal incentives. It also means using on-site heat and energy storage whenever possible. Such homes must also include very well designed and efficient ventilation systems, which use electricity to maintain a healthful indoor air quality. This is now possible with humidity-based control strategies used with well-designed ventilation systems, which are integral to new housing construction. Retrofit will always be more expensive, but the technologies now exist and the control strategies are on the verge of maturity.

It may be difficult to accomplish an economical "zero net energy" home design for Alaska. But with a large hydrogen and/or natural gas infrastructure system, which may be on the horizon for Alaska, that becomes more feasible. Seasonal storage of energy could by done within the infrastructure of a hydrogen distribution system, thus accommodating seasonal storage of a renewably generated heat supply.

Much depends on decisions we make, and the housing we build now and in the future. The more energy-conserving, durable, and materials-efficient we can make our housing and the more comfortable and healthful those materials are, the better our lives will be.

introduction

This manual is an attempt to assemble all the Alaska-specific solar energy design information in a single volume. The manual is organized according to the following major subject areas:

The first section is an introductory background discussion of solar energy and some of the important physical concepts necessary to understand it. This is followed by a discussion of Alaska-specific considerations regarding solar energy.

The next major section deals with the technologies used in solar energy applications. The discussions include both active solar energy technologies, where heat is moved by pumps from the collectors to a point of use, and passive systems, where heat is moved within a building through natural means. Passive solar energy applications generally include those in which the structure itself is used as the collector. Discussion of photovoltaic cells, which produce electricity directly from solar energy, are a major emerging option. That discussion is greatly expanded in this second edition. Energy storage is discussed because it is very important to the prospect of renewable energy use at high latitudes. Storage of energy is a general need in all intermittent renewable energy applications.

A third section describes the heating of domestic or commercial hot water using solar energy. This section discusses factors such as the solar geometry at high latitudes, shading, and snow cover effects, all of which influence the performance of solar hot water heating systems.

Active solar space heating systems are covered and methods for using hybrid storage and hydronic systems are described.

The final section describes passive solar design applications in the far North. Examples of classic passive solar design options are analyzed, and a physical optimization of a building design is included.

A Short Course In Solar Energy

Solar energy is radiation; most solar technologies capture this radiation as heat. Other technologies use solar energy directly for day lighting or for generating electricity.

Visible light is the largest component of solar radiation, and it is the portion of the spectrum that can be usefully converted to heat. Wavelengths shorter than visible light (called ultraviolet) are largely absorbed in the upper atmosphere. The other major component of solar radiation, infrared, has longer wavelengths than visible light. We perceive infrared radiation as heat. A hot object emits infrared radiation, allowing us to sense the object without touching it.

The amount of available solar radiation is not constant. Solar altitude at midday and day length vary with the season. Light intensity changes with the time of day. Environmental conditions further modify the amount of solar energy that the earth receives at a particular location or time. Yet the sun does emit a relatively constant amount of radiation with time. Referred to as the **solar constant,** the amount of solar radiation at the outside of the atmosphere facing the sun is 428 BTU/ft^2/hr (~ 1350 watts/m^2). A BTU (British Thermal Unit) is the amount of heat needed to raise the temperature of a pound of water by 1°F. In the metric system (commonly used outside the United States), heat is expressed in calories. A calorie is the amount of heat needed to raise the temperature of a gram of water by 1°C.

As solar radiation passes through the atmosphere, some continues in a straight path and some is scattered by the atmosphere. The former is called **beam radiation** and the latter is called **diffuse radiation.** Beam radiation enables shadows to be cast, and diffuse radiation is characteristic of overcast days.

Solar radiation received on a surface is usually a combination of both beam and diffuse radiation. Diffuse radiation comes from all directions in the sky, so it cannot be focused. It is still useful to those solar heating systems that don't require focusing of the solar radiation. Some light striking an object on the earth's surface (or anywhere else) will be reflected and some will be absorbed by the object. The ratio between the amounts of absorbed and reflected radiation is called the **solar absorptance.** A solar absorptance of 0.94 means that 94 percent of the solar energy striking a surface is absorbed. This energy is absorbed as heat. Some of this heat will be lost to the surrounding environment.

Heat can be transferred by conduction, convection, or radiation. **Radiation** is the transfer of energy by electromagnetic (light) waves. This flow occurs at the speed of light, even through a vacuum. Thermal radiation is largely restricted to the infrared wavelengths, which are invisible to man.

Conduction is the transfer of heat to adjacent molecules in a substance. The handle of a cast iron skillet gets hot during use by conduction, but the wooden handle of an aluminum skillet does not. Obviously, cast iron is a good conductor while wood is an insulator. Conduction operates in any substance whether solid, liquid, or gas.

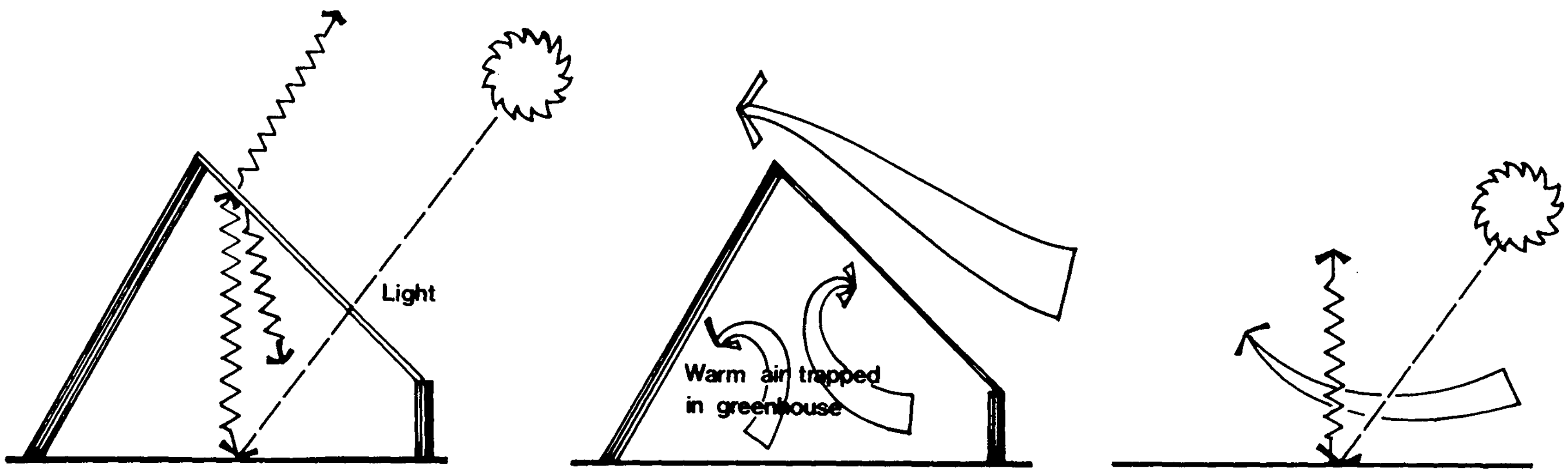
Convection is the transfer of heat from one object to another by an intermediate fluid (liquid or gas). Convection can occur naturally as hot air rises and cools (as it does in a thunderstorm). Or convection can be mechanically driven (like the fan on an automobile engine which cools the radiator by drawing air across it).

Visible light can penetrate glass but infrared radiation does not pass through glass as well. This is why greenhouses tend to be warmer than the outside temperature. Visible light penetrates the glazing. Some is reflected from the materials inside the greenhouse; this radiation can pass through the glazing to the outside. The absorbed radiation warms the objects, and some of this heat is lost in the form of infrared radiation to the air and other objects inside the greenhouse. Since the glazing is nearly opaque to infrared, the inside air temperature increases. This phenomenon is sometimes referred to as the **greenhouse effect.** A greenhouse can be regarded as a simple solar collector since it is a radiation and convection trap (Figure 2).

Greenhouses are effective collectors, but unless the glazing is insulated during periods when it is not receiving heat from the sun, greenhouses will lose heat very rapidly by conduction and convection. This is because greenhouses commonly do not have the built-in capacity to store heat. To overcome this design problem, "solar greenhouses" can be built which incorporate thermal storage to cut down or eliminate the need to heat greenhouses with fossil fuels at night or during long cloudy periods. "Solar greenhouse" sounds redundant, but solar in this case is an adjective used to indicate that the greenhouse is heated by the sun entirely or to a maximum feasible extent, as opposed to the common practice of using fossil fuels to heat it when necessary.

The solar heating of a greenhouse is accomplished through passive solar means. Heat is stored in concrete, rocks, water or antifreeze drums, or gravel during the day when excess heat is available. This stored heat is then released to the greenhouse interior at night.

Attaching a greenhouse to the south side of a house so that excess heat from



A

Some light entering the greenhouse is absorbed, some is reradiated as infrared radiation which is trapped, some escapes through reflection and conduction.

B

Warm air, heated by trapped infrared radiation, warms the greenhouse.

C

The absorption, reradiation and convection of heat away from the surface of the earth as it naturally occurs without a greenhouse present.

Figure 2. The physical interactions occurring in a greenhouse.

the greenhouse can be used to help heat the house is another common solar heating option. It may also be a valuable technique in Alaska (see Figure 3).

Common Applications Of Solar Energy

Daylighting

The use of visible solar radiation to reduce or eliminate the need for artificial lighting in a building is commonly called daylighting. This obvious function of sunlight is sometimes overlooked, yet it can provide substantial economic benefit. It is the oldest and most common use of solar energy.

Photovoltaics (solar electricity)

Solar energy can be directly converted to electricity using photovoltaic cells. This application is widely used where power is needed in remote Alaska locations. Photovoltaics in Alaska have made great advances in the twenty years since the first edition of this manual was written. Photovoltaic electricity production has become by far the most successful and widely adapted solar energy application in Alaska. First developed for remote sites by individuals, it is also used by federal agencies and the military for communications, repeaters, utilities, and directional and navigational beacons.

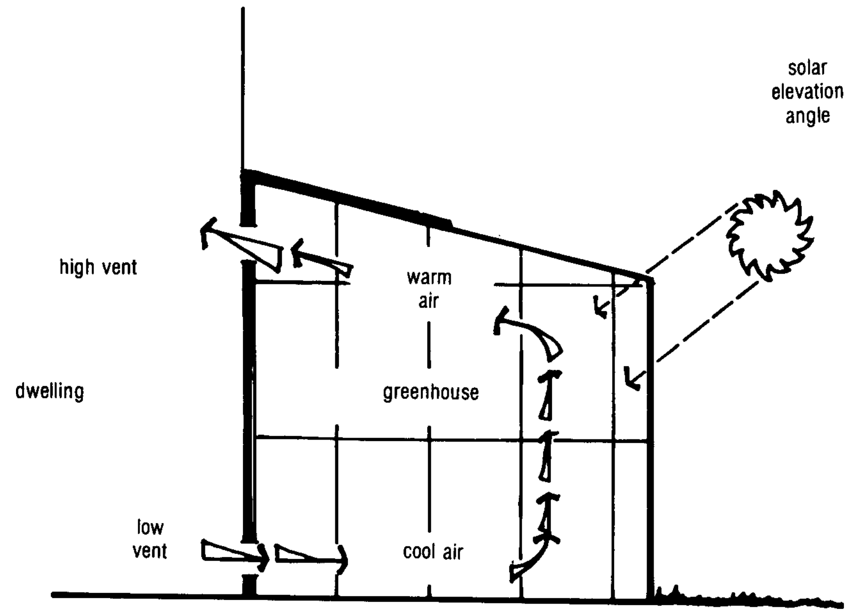


Figure 3. An attached solar greenhouse (also called a sunspace). Heat that is not needed in the greenhouse can be vented to the living area of the home.

Alaska now has more than 160 kilowatts (2002 estimate) of installed capacity and the installation rate is increasing. Alaska joined other states and communities in forming a "Million Solar Roofs Coalition," the first organized advocacy and information outreach effort devoted to solar renewable energy (funded by the U.S. Department of Energy) in more than fifteen years. Members of this voluntary coalition include businesses, advocates, utilities, and technicians who have an interest in solar energy use and development. Most of the coalition's efforts are directed toward off-grid electrical power production and power supplies for remote sites. (Off-grid simply means a location where utility "grid" electrical power is not available.) A website: www.alaskasun.org, where this manual is available as a PDF, is maintained by author Rich Seifert. Other on-line resources include: www.eren.doe.gov/millionroofs and www.nrel.gov. Also, each Alaskasun member's website is listed on the member's page on www.alaskasun.org, and you are urged to visit that page to learn of dealers and members in your region of Alaska.

In this third edition of the manual a new section has been added to address the importance of photovoltaics, and to better aid Alaskans who wish to apply this energy resource.

Active Heating

Active solar technologies employ an auxiliary energy source to move heat from where it is collected to where it is used or stored (usually by a pump or fan). Active solar technologies are practical for providing domestic hot water in Alaska. They may ultimately prove to be useful for space heating (particularly if installed on already existing structures), but there is little experience with active solar space heating in Alaska.

Passive Heating

Passive solar applications capture heat without the need for auxiliary energy to move the heat. Chiefly used for space heating, passive solar technologies move heat by conduction, convection, or radiation. The building employs south-facing glazing to capture solar radiation, essentially making the entire structure a simple solar collector.

Solar Energy In Alaska

The potential for using solar energy in Alaska has long suffered from the notion that the sun simply doesn't offer any hope for Alaskans. From roughly November 15 until the end of January, little solar radiation is available, and optimizing a system to collect it is not economically feasible. So what can the sun provide?

There are 230 hours more of possible sunlight at the Arctic Circle than at the equator. The problem with solar energy is that it is dynamic, not reliable, and is out of phase with the space heating loads in the state. Yet solar energy is on-site, and not subject to transportation system failures. It creates few environmental problems. Solar energy is not inflationary, and is relatively evenly spread across the planet.

Solar energy has many benefits not usually considered. In addition to fundamental security, solar energy is clean and safe. Once manufactured, there are no air pollution problems from solar equipment. Unlike the cost of depletable resources, which rise exponentially as reserves are depleted, the cost of energy from the sun should decline as we develop better and cheaper ways of using it.

It is clear that solar energy is a valuable resource for Alaskans if it is properly understood and cleverly and efficiently used. Here are recommendations on the best ways to use solar energy:

1. The **solar heating of hot water** for domestic or commercial use is a viable option for many regions of Alaska. Anchorage is presently a major exception because inexpensive natural gas is available. Although it is not economically reasonable to

heat 100 percent of hot water needs year-round, an investment in solar water heating is warranted in many Alaska cities and villages. Hot water is needed year-round, and solar energy is available and useful for this purpose. This prospect is developed more completely in the section on solar heating of domestic and commercial hot water.

2. **Collector tilt** for active (pumped) systems is not crucial. It is recommended that collector arrays be mounted on the south wall or on the ground in Alaska at a 90° tilt. Vertical south wall mounts do not yield optimum collection of energy, but they do eliminate snow and dirt accumulation and are easier to mount. Roof penetrations are also avoided. Ground mounts enable easier cleaning of collectors and removal of snow.

3. **Active solar systems for space heating** are a less economic option than their passive counterpart. Because of the extreme annual variation of available solar radiation in Alaska, it is difficult to obtain more than 25 to 35 percent of the annual heating requirements for even a highly insulated structure. Although annual or long-term heat storage systems may alter this situation, storage systems are not perfected, not readily available, nor inexpensive. Because of the high cost of solar hardware, the best approach to solar space heating is to optimize the house or building to be heated *first* for energy efficiency, including its appliances and lighting. By investing in a durable and highly energy efficient housing stock for Alaska, not only will our citizens have more affordable homes, but the need for energy is less. Particularly for solar and renewable energy, the cheapest energy available is conserved energy, i.e., that which you'll never have to buy because you lowered the demand with optimal insulation and appliances in the home to start with. This holds true regardless of whether the solar (or any renewable) energy is used for heating or electricity.

4. **Passive solar design in Alaska** can be useful and economical. The most common approach to passive solar design is to maximize the use of south-facing windows in a structure and use good conservation design throughout (good vapor barrier, weatherstripping, large amounts of insulation, and insulated shutters, as mentioned above).

5. **Shutters** are crucial for effective passive solar design in Alaska. Without shuttering, passive solar designs cannot be efficient, and large window areas will lose a great deal of energy. The effects of shuttering are discussed in the passive solar design section. Windows are clearly the most important element in passive solar designs. Although shutters are not now used in passive solar designs, they are still a good idea. New window technologies such as low emissivity, "Heat Mirror,"® glazings, and the SPACIA evacuated glazing technology are both great prospects for passive solar use, but they are not of the insulation value needed to make shutterless passive solar designs really beneficial. What is needed is to make glazings that have an insulating value of R 8 to 10, instead of the R 3 to 4 presently common in low emission and vacuum technologies. Shutters still prevail in any optimization of passive solar design at high latitudes. This is because all window technologies are net losers in December when heat is most needed and the sun is least available in Alaska.

Availability of Solar Radiation

Generally, the availability of solar energy is directly related to latitude, because the intensity of solar radiation is proportional to the angle of the sun above the horizon (solar elevation). However, due to the climatic effects of oceans, mountains, and other geographical relationships in Alaska, solar radiation does not correlate well with latitude. Rather, it is related to the physiography and the amount of rain shadowing due to the large Alaska mountain ranges such as the Chugach and Alaska ranges. This rain shadowing isolates the interior and continental climatic regions of Alaska from cloudy weather and precipitation. For these reasons, practical applications of solar energy are feasible in the continental and transitional areas of Alaska. Both of these areas dominate the Alaska railbelt (see Figure 4). The definitions of these areas are given below.

Transitional: Pronounced temperature variations throughout the day and year, low precipitation and humidity. Surface winds generally light. Mean annual temperature generally 25 to 35°F.

Continental: Dominated by continental climatic conditions. Great diurnal and annual temperature variations, low precipitation, low cloudiness, and low humidity. Surface winds generally light. Mean annual temperature 15 to 25°F.

Since the sun's rays strike the ground at a lower angle at higher latitudes, the energy received on the ground surface is less than it would be if radiation struck from directly overhead. Thus, radiation intensity is less than at lower latitudes. In summer, however, the days are longer and total daily radiation received is approximately equal to that at lower latitudes (Hartman and Johnson, 1978).

A second facet of the solar resource in Alaska is the annual variability. Not only does day length change from approximately 3½ to 4½ hours in winter to 20 to 22 hours in summer, but the elevation angle varies from a meager 2.6° above the horizon on December 21 in Fairbanks to 49½° above the horizon on June 21. The sun is never overhead (at 90°) in Alaska. The maximum height it can reach above the horizon for any place can be calculated by subtracting the latitude from 113½°. Thus at 64°N the highest the sun reaches is 113½° – 64° = 49½°.

Table 1 gives some idea of how solar radiation in Alaska compares to other latitudes. It shows the percentage of the year that is twilight, sunlight, and a sum of both at latitudes from the equator (0°) to 75°N. Note that sunlight, twilight, and all light combined reach a maximum at 70°N, about the latitude of Barrow, Alaska.

It is clear from Table 1 that Alaska latitudes receive, on an annual basis, a small bonus of extra sunlight and a large bonus of extra twilight compared to lower latitudes. The sun, in rising or setting, crosses the horizon at a shallow angle at the northern latitudes and consequently takes longer to rise or set. This lengthens the day slightly and the twilight a great deal. In addition, refraction (the bending of the sun's rays by the atmosphere) lengthens the day by making the sun visible even when it is below the horizon. Refraction is small in the tropics but fairly large in Alaska, particularly during the winter (Hartman and Johnson, 1978). Another means of understanding the solar variation at Alaska latitudes is to study the sun's orientation with time (see Figure 5).

Figure 5 shows that in order to get the maximum (called "normal" or "perpendicular") radiation, it is necessary to change the tilt of a surface from the horizontal. Optimum tilts for each season are shown.

Figure 6 shows geometrically why solar intensity is related to the elevation of the sun. The intensity of the sun is maximum on a surface oriented at right angles ("normal" or "perpendicular") to it. As the solar elevation decreases both during the day and seasonally, the same amount of radiation is spread

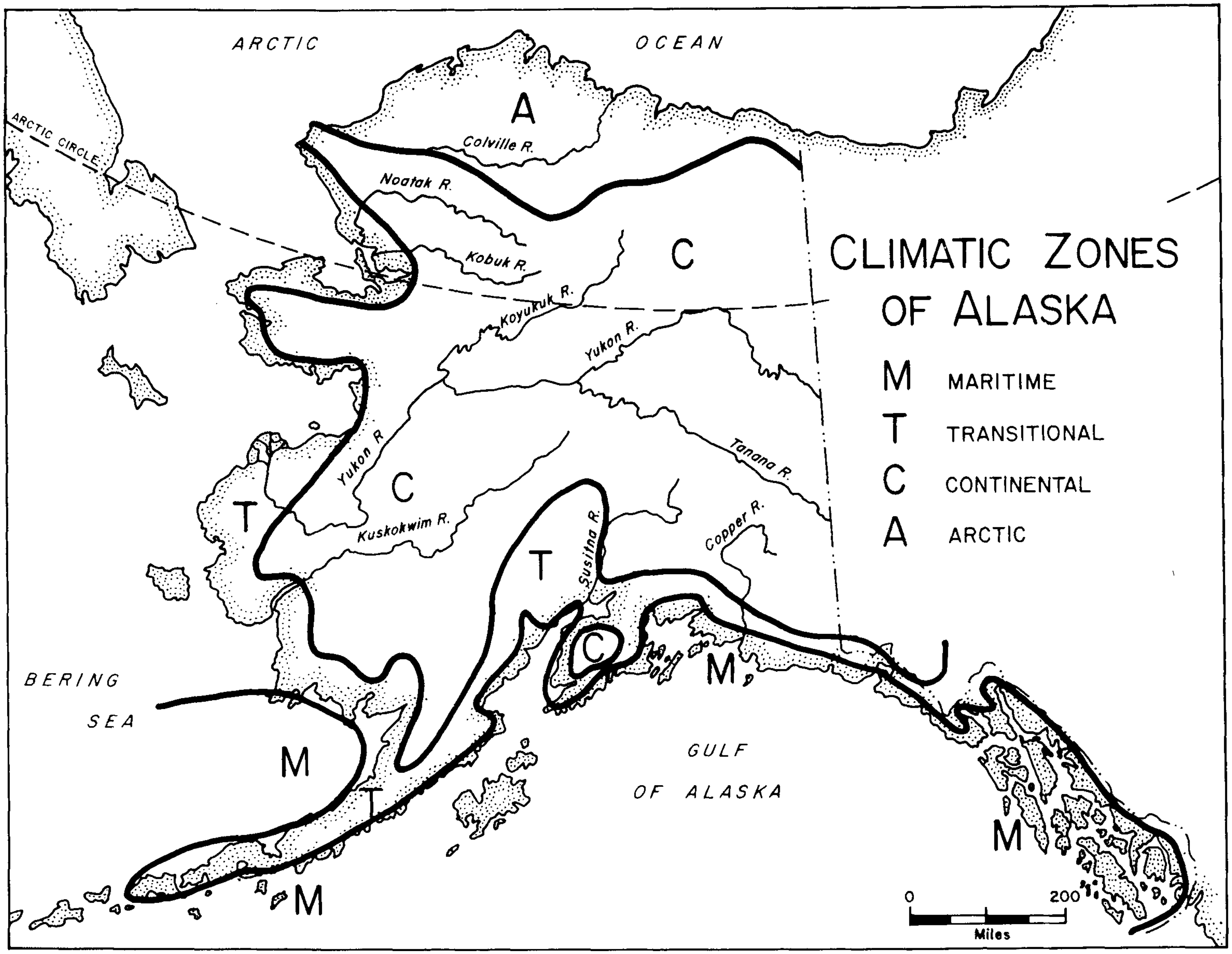


Figure 4. Climatic zones in Alaska. There is a correlation between the climatic zones of Alaska and the annual available solar energy. The continental zones yield the most available annual solar radiation. The transitional zone and arctic zone have the next highest. The maritime climatic zone is characterized by cloudy, rainy weather and is a less suitable climate for solar energy applications.

over increasingly more and more area. Therefore, the amount falling on each unit area is less.

TABLE 1: PERCENTAGE OF THE YEAR THAT IS TWILIGHT, SUNLIGHT, OR BOTH AT VARIOUS LATITUDES (Hartman and Johnson, 1978).

Latitude °N	Twilight %	Sunlight %	Sunlight and Twilight %
0	3.10	50.30	53.40
25	3.49	50.50	53.99
35	3.92	50.60	54.52
45	4.68	50.75	55.43
55	6.24	51.30	57.27
60	8.11	51.28	59.39
65	10.39	51.87	62.26
70	10.94	51.97	62.91
75	8.93	51.89	60.82

Further Web-Based Solar Information

The best source of solar information and access to other resources, products, education, and government resources is:

www.ases.org

This is the site of the American Solar Energy Society. It links (simply click on the "USEFUL LINKS" button) to most of the best renewable and related energy sites. They are listed alphabetically and described with a brief annotation. Just go there and explore!

Visit also: **www.alaskasun.org**

www.sustainalaska.org

and our Extension website:

www. uaf.edu/coop-ext/faculty/seifert/

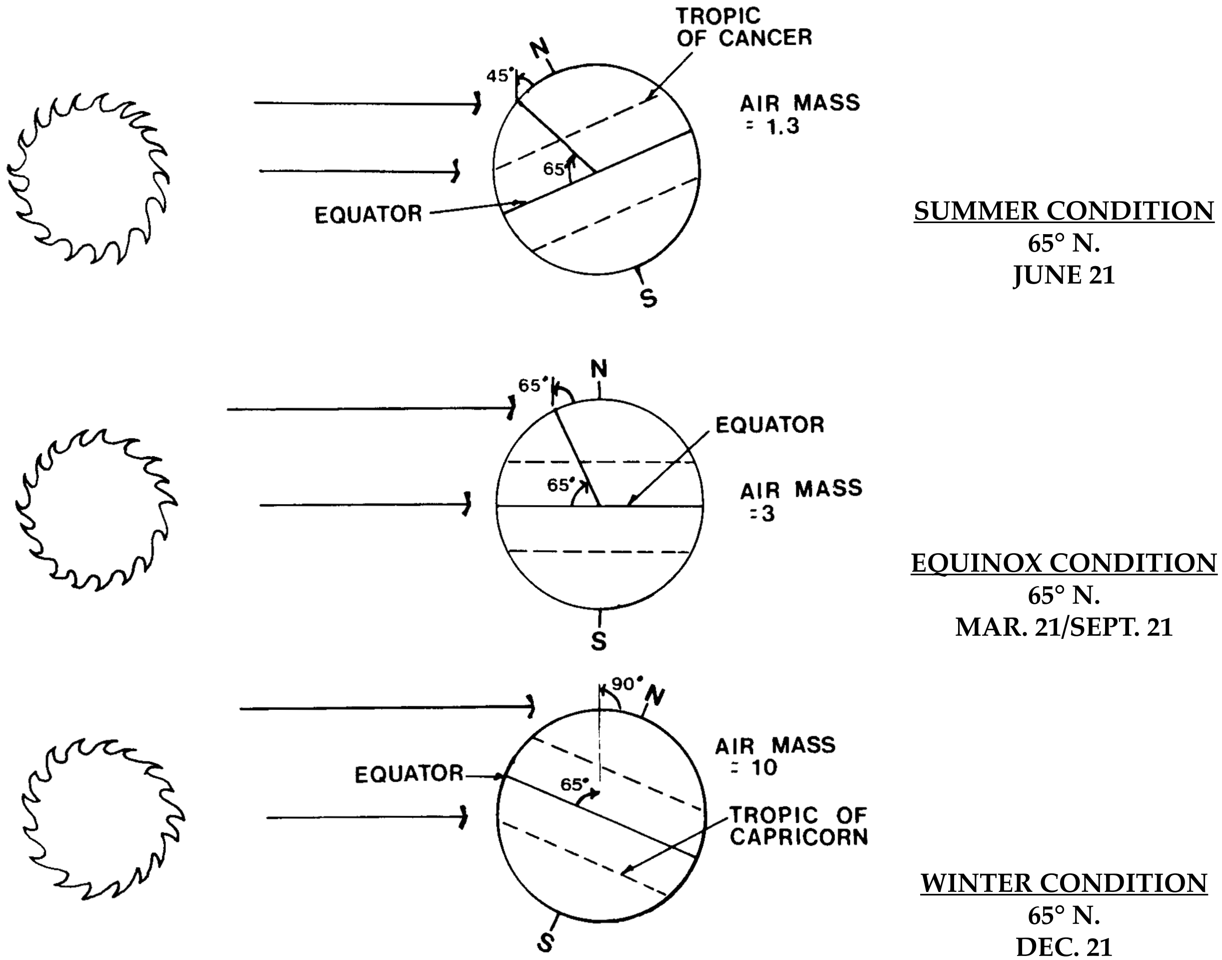


Figure 5. Basic solar geometry at noon during different seasons, showing how the changing effects of seasonal solar elevation affect the optimum tilt of a surface for collecting solar energy. The air mass is an indicator of the absorption of solar energy in the atmosphere due to the increasing thickness of atmosphere that solar energy must pass through before reaching the surface of the earth. This air mass is proportional to the secant of the solar elevation angle (1/cosine).

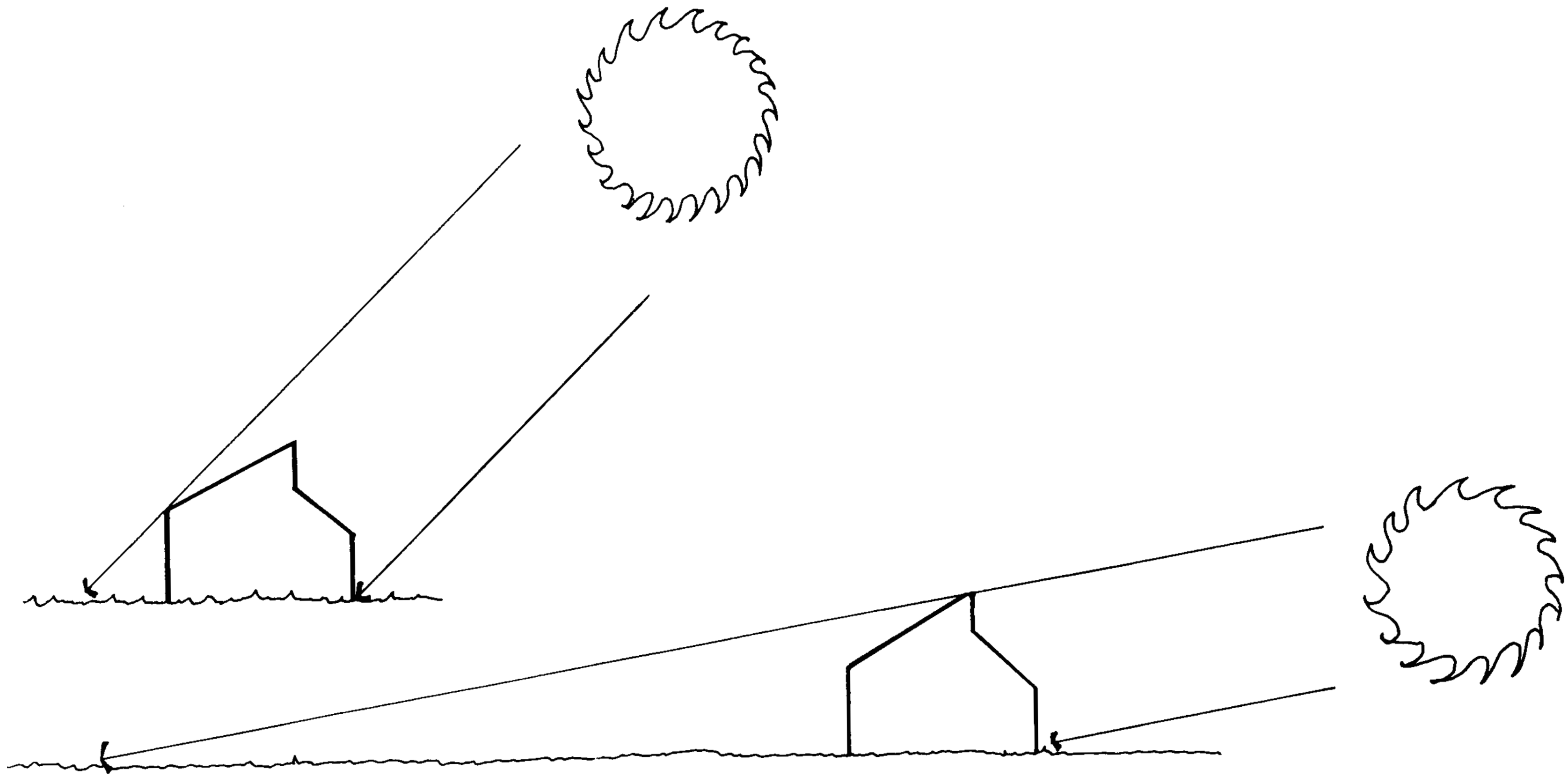


Figure 6. Elevation of the sun and its relationship to the intensity of energy striking a horizontal surface. The amount of solar radiation striking the top of the atmosphere is similar at different times of the year. Yet the intensity (amount) of radiation striking each square foot of surface area is less during winter, because the radiation is spread over a much larger area at low solar elevation angles. The radiation at low solar elevation angles is further diminished because it travels through more of the atmosphere, allowing more scattering and atmospheric absorption. Since at the top of the atmosphere, the intensity of solar radiation is everywhere equal on a surface perpendicular to the sun, the elevation angle (number of degrees above the horizon) and the amount of atmosphere the radiation passes through are very important variables. The result is that the same amount of solar radiation is spread over ever-larger areas as the sun gets lower and lower in the sky.

Figure 7. Map of Alaska showing locations of towns for which sun path diagrams are provided (see pages 59 through 82.)